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Unsafe acts and unsafe outcomes in aircraft maintenance

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Road safety studies using the Driver Behaviour Questionnaire (DBQ) have provided support for a three-way distinction between violations, skill-based errors and mistakes, and have indicated that a tendency to commit driving violations is associated with an increased risk of accident involvement. The aims of this study were to examine whether the three-way distinction of unsafe acts is applicable in the context of aircraft maintenance, and whether involvement in maintenance safety occurrences can be predicted on the basis of self-reported unsafe acts. A Maintenance Behaviour Questionnaire (MBQ) was developed to explore patterns of unsafe acts committed by aircraft maintenance mechanics. The MBQ was completed anonymously by over 1300 Australian aviation mechanics, who also provided information on their involvement in workplace accidents and incidents. Four factors were identified: routine violations, skill-based errors, mistakes and exceptional violations. Violations and mistakes were related significantly to the occurrence of incidents that jeopardized the quality of aircraft maintenance, but were not related to workplace injuries. Skill-based errors, while not related to work quality incidents, were related to workplace injuries. The results are consistent with the three-way typology of unsafe acts described by Reason *et al.* (1990) and with the DBQ research indicating an association between self-reported violations and accidents. The current findings suggest that interventions addressed at maintenance quality incidents should take into account the role of violations and mistakes, and the factors that promote them. In contrast, interventions directed at reducing workplace injury are likely to require a focus on skill-based errors.

1. Introduction

Most transport and industrial accidents are triggered by unsafe human actions, although accidents may also reflect longstanding system deficiencies (Hale and Glendon 1987, Reason 1990, Feyer *et al.* 1997). In attempting to understand the unsafe behaviours that contribute to accidents, researchers and investigators have drawn on error models developed by cognitive psychologists or engineers. Such models typically distinguish between two forms of cognitive failures, the first being the failure to carry out actions as intended, the second being 'mistakes' in which erroneous thinking leads to incorrect, but intended actions (Norman 1981).

It is apparent, however, that unsafe behaviours in safety-critical environments stem not only from failures of information processing and action execution, but also

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reflect intended deviations from rules and procedures. Mason (1997) reports that deliberate deviations from recommended safe behaviour may be involved in 70% of accidents in some industries. According to Reason *et al.* (1998), intentional non-compliance with procedures is a significant problem in fields as diverse as oil production, rail transport and medicine. The problem also features significantly in aviation safety. Lautman and Gallimore (1987) found that pilot deviation from basic operational procedures featured in 'crew caused' airline accidents more frequently than any other form of behaviour. On the roads too, driving offences are associated with increased accident risk. Rajalin (1994) found that motorists involved in fatal accidents had a higher rate of traffic offences than other road users, while Elander *et al.* (1993) provide evidence that driving speed is an important determinant of crash involvement.

Given the significance of violations in a diverse range of safety environments, it is apparent that models of unsafe behaviour must be able to take into account not only cognitive failures, but also intentional rule-breaking and the factors that lead to such behaviour. In expanding Rasmussen's (1983) skill-rule-knowledge framework, Reason (1990) acknowledged the importance of intentional violations and placed such actions into his general model of unsafe acts. His model has resulted in widespread acceptance of a three-way distinction between unintended errors, mistakes and violations.

A range of data sources have been used in the study of unsafe acts, including accident reports, critical incidents, experiments and simulations (Patrick 1987). Participant-completed checklists have also been used widely by error researchers. Checklists such as the Cognitive Failure Questionnaire (Broadbent *et al.* 1982) and the Driver Behaviour Questionnaire (DBQ) of Reason *et al.* (1990) offer a number of benefits. Most notably, they enable a large amount of data to be gathered on a range of 'everyday' unsafe acts, and permit naturally occurring patterns of unsafe acts to be identified. The checklist approach also enables the association between unsafe acts and demographic variables (such as age and industry experience) to be explored. Perhaps most importantly, checklist data can be used to identify associations between unsafe acts and accidents or other safety occurrences.

Several checklist studies of driver behaviour have provided support for the distinction between errors and violations. Reason *et al.* (1990) developed a Driver Behaviour Questionnaire (DBQ) that includes questions on skill-based behaviour, mistaken intentions and violations. A factor analysis of responses by 520 drivers identified three factors, which Reason *et al.* (1990) labelled violations, harmless lapses and dangerous errors. A further study of 1600 drivers (Parker *et al.* 1995) confirmed this factor structure and demonstrated that accident liability was related to self-reported tendency to commit violations, but was not related to lapses or other errors. The factor structure of the DBQ was replicated subsequently by Åberg and Rimmöe (1998) who went on to add new items to the questionnaire, enabling it to distinguish between errors of inattention and errors of inexperience. Further evidence for the distinction between errors and violations has been provided by Blockey and Hartley (1995), who administered a version of the DBQ to a small sample of drivers in Western Australia. While the factor structure that emerged from their data did not correspond precisely with that found by Reason *et al.* (1990) it did result in violations and errors being placed in separate factor categories, although no relationship was found between accident history and scores on any of the three factors. It remains to be seen, however, whether behavioural questionnaire data from outside road safety will support the above distinctions between unsafe act types, and whether further correlational evidence can be obtained to support an association between specific types of unsafe acts and safety occurrences. The demonstration of such links in a context other than driving would help to clarify the role of various forms of unsafe acts in safety, and would assist in identifying targets for safety interventions.

The study of error in air transport has until recently been largely confined to the actions of aircrew (Green 1990) or air traffic controllers (Langan-Fox and Empson 1985). During the 1990s however, many in the aviation industry turned their attention to the poorly-understood problem of maintenance error. Maintenance deficiencies have been estimated to be involved in approximately 12% of major aircraft accidents and 50% of engine-related flight delays and cancellations (Marx and Graeber 1994). Seemingly minor deviations from maintenance procedures, whether deliberate or unintentional, can result in consequences that are at best expensive and at worst calamitous. According to Russell (1994) deficient aircraft maintenance contributed to the deaths of 1481 airline passengers worldwide in the years 1982–1991.

In general, researchers who have examined aircraft maintenance anomalies arising from human error have focused on the outcome of the error as described in incident reports, rather than the nature of the error itself (International Civil Aviation Organization 1995, Rankin 1996). In a critical incident study of maintenance errors and the context in which they occur, Hobbs and Williamson (2002) found that skill and rule-based errors predominated. This appears to reflect the demands of the job, which largely requires workers to engage in skill-based and rule-based activities. There is also evidence however, that violations are an important class of unsafe act in aircraft maintenance. In a study of the normal job performance of 286 aircraft mechanics, McDonald *et al.* (2000) found that 34% acknowledged that their most recent task had been performed in a manner that contravened the formal procedures.

This paper deals with the development and application of a maintenance version of the DBQ, which was used to explore the nature of unsafe acts in aircraft maintenance and the relation of such acts to safety occurrences. The first aim of the present study was to examine whether the three-way distinction made by Reason (1990) between unintended errors, mistakes, and violations is appropriate in the context of aircraft maintenance. The second aim was to assess whether the relationship between different types of unsafe behaviour and safety outcomes found by Parker *et al.* (1995) in road safety would also be evident in aircraft maintenance.

2. Method

2.1. *Development of the Maintenance Behaviour Questionnaire (MBQ)*

Critical incident interviews were conducted with 72 airline mechanics employed by major airlines in the Asia-Pacific region. Participants were asked to describe an incident that they had been involved in or observed in the last 12 months. An incident was defined as any situation in which events occurred that could have prevented an aircraft from operating normally, or could have put the safety of anyone (including maintenance workers) at risk. A structured interview form, based on the critical incident technique described by Flanagan (1954), was used to collect information on the nature of each incident, and any human involvement that may have led to it. In order to encourage open reporting, reporters' names were not linked to incidents and reporters were given the option of requesting that incident details remain confidential. A collection of 101 incident reports was compiled, 95% of which involved the actions of maintenance workers. This stage of the project is discussed in more detail elsewhere (Hobbs and Williamson 2002).

The reported unsafe acts were condensed into a list of 43 actions. This list was then discussed with a panel of air safety investigators who possessed specialized maintenance experience. The investigators ensured that each action represented genuinely unsafe behaviour and was expressed in appropriate terminology. As a result of these discussions, five additional unsafe acts were added to the list. The 48-item list was then reviewed by the panel, and the wording of several items was further clarified to ensure that in the view of the panel, only one technical meaning could be attached to each item. The final bank of 48 items contained 21 violations, nine mistakes, four slips, nine lapses, four actions that could be categorized as either slips or mistakes, and one action that could be interpreted as either a lapse or a mistake. The high proportion of violations reflected the frequent appearance of such actions in the critical incidents described by maintenance mechanics, while the small number of slip items was because these errors were mentioned relatively infrequently.

The 48 items were consolidated into a checklist, the Maintenance Behaviour Questionnaire (MBQ), which formed part of a larger maintenance safety survey. A trial version of this survey was administered to 40 mechanics who were attending a union delegates' conference. Each person was asked to make a note of any problems they had experienced in completing the survey form. No difficulties were identified with the MBQ, although several items requiring modification were identified in other sections of the safety survey not related to the MBQ.

2.2. *Participants*

The survey was distributed to approximately 4600 aviation mechanics, representing all aircraft mechanics who hold maintenance licenses issued by the Civil Aviation Safety Authority of Australia. In addition, approximately 300 unlicensed mechanics received the questionnaire by post from their employers. A total of 1359 questionnaires were returned, representing a response rate of approximately 28%.

Nearly 70% of the respondents worked in the airline industry and the majority of these respondents were employed by major airlines (table 1). Those who reported that they were not currently working in the aircraft maintenance industry were excluded from further analysis. The average period that respondents had worked in the industry was 24 years (SD = 10.6 years). A total of 93.7% of the respondents were licensed aircraft maintenance engineers, 5.6% were unlicensed mechanics while

Table 1. Industry sector in which respondents were employed.

Category of aircraft maintained	Number of respondents	Percentage
Major airline	820	60.3
Regional airline	125	9.2
Charter	179	13.2
General aviation	125	9.2
Other maintenance work	43	3.2
Not given	9	0.7
Not working in industry	58	4.3

0.8% had other qualifications. The age distribution of the respondents was as shown in table 2. Although the average age cannot be calculated from this categorical data, it can be seen that the greatest number of respondents were in the 31–40 years age group.

2.3. *Procedure*

Following a series of introductory statements concerning the need to gather information on maintenance safety, respondents were asked to judge how often they had performed each of the actions described in the MBQ in the last year or so. The instructions made it clear that a 'best guess' rather than a precise answer was adequate. Each action statement appeared alongside a 5-point Likert scale where 1 = 'Never', 2 = 'Very rarely', 3 = 'Occasionally', 4 = 'Often' and 5 = 'Very often'. In addition, respondents had the option of responding 'Not relevant to me' for each item.

In a later section of the survey respondents were asked to provide a range of demographic details, including their age, the years they had worked in the aircraft maintenance industry, and whether they currently had supervisory responsibilities. In addition, respondents were asked to nominate the category of aircraft that they maintained. The following definitions were used: 'major airline' aircraft were defined as those having more than 38 passenger seats; 'regional airline' aircraft were defined as those having up to 38 passenger seats; 'charter aircraft' are used for non-scheduled commercial transport and are generally piston-engined unpressurized aeroplanes. 'General aviation' aircraft are light aircraft primarily used for personal business or pleasure flying. Where a respondent reported that they maintained aircraft from more than one of these categories, they were assigned to the category associated with the largest aircraft type maintained. Respondents were also asked to report details of any work injuries that they had sustained in the last year, and whether they had been involved in a maintenance quality problem that had affected the operation of an aircraft. Maintenance quality problems are incidents that result in consequences such as an in-flight diversion or return to the departure point, delay, or damage to an aircraft or component.

Respondents were asked to return the completed survey form anonymously in a reply-paid envelope. To encourage participation, a lottery was run with 5 prizes ranging from pen knives to $500 worth of tools. Through the use of security codes, respondents were able to enter the lottery draw without the need to identify themselves.

Table 2. Age distribution of respondents.

Age (years)	Number of respondents	Percentage
<21	1	0.1
21–30	202	15.6
31–40	407	31.5
41–50	358	27.7
51–60	245	19.0
61–70	62	4.8
>70	9	0.7
Age not given	8	0.6

2.4. *Data analysis*

Maintenance Behaviour Questionnaire responses were subjected to a principal components analysis (referred to here as a 'factor analysis') with varimax rotation using SPSS for Windows, v. 8.0 (SPSS Inc., Chicago, ILL). Missing data were excluded pairwise in order to reduce the number of cases lost due to 'not relevant' responses. The number of factors to be extracted was determined using the scree plot as recommended by Stevens (1992). Once factors were extracted, overall factor scores were obtained by calculating the mean score for those items with factor loadings of 0.4 or greater. Factor scores were then entered simultaneously into multiple regression equations as dependent variables, with demographic data (such as age and employment type) entered as independent variables. This procedure permitted the association between demographic variables and factor scores to be established. Qualitative variables, such as the type of aircraft maintained and whether the person was a supervisor, were converted to dummy variables where 0 represented 'no' and 1 represented 'yes'.

In the final stage of the analysis, factor scores and demographic variables were entered into two hierarchical regression equations with involvement in quality incidents and workplace injury as the respective dependent variables. In each case, the dependent variable had two possible values, with '0' representing no occurrences in the last year and '1' representing at least one occurrence in the last year. Those demographic variables which predicted at least one factor score at the 0.01 level of significance were entered into regression equations before factors scores.

3. Results

3.1. *Maintenance Behaviour Questionnaire*

Table 3 presents the mean response to each MBQ item, in addition to the type of behaviour it was judged by the researchers to represent. As can be seen, for most items, the average response was in the range between never (1) and very rarely (2). Some behaviours, such as 'accidentally starting an engine' or 'adding the wrong fluid to a system' received particularly low frequency ratings.

3.2. *Factor analysis*

The scree plot indicated that a four factor solution would be most appropriate, hence four factors were extracted and subjected to varimax rotation. The four factors together accounted for 37.3% of the variance in MBQ item scores. Factor loadings on the four rotated factors are presented in table 4. As loadings below 0.4 may be of no practical significance (Stevens 1992), such loadings were not used in naming factors, and are not reported here.

The first factor was labelled 'routine violations' after Lawton (1998) who defines such violations as rule-breaking actions that have become the normal way of working. The average frequency ratings for items loading on this factor was relatively high, at 2.13 and of the 18 items with loadings of 0.4 or greater on this factor, all but one were judged to be violations. The exception was item nine, with a loading of 0.5, which was categorized as a 'mistake'. This factor accounted for 12.3% of the variance of the MBQ.

Factor 2 was labeled 'skill-based errors'. Of the 12 items with loadings of 0.4 or more on this factor, eight were memory lapses or potential memory lapses, and two were potential slips. The average frequency rating of factor 2 items was 1.54. This factor accounted for 10.0% of the variance.

Table 3. Means and standard deviations for MBQ items, arranged in order of frequency of occurrence.

Item	Description	Type*	Mean	SD
12	Not referred to the maintenance manual or other approved documentation on a familiar job	V	3.18	1.11
4	Been misled by confusing documentation	M	2.84	0.87
33	Pulled a circuit breaker but decided not to tag it	V	2.79	1.16
11	Done a job without the correct tool or equipment	V	2.76	0.94
15	Not documented a small job	V	2.76	1.06
43	Dropped an object into a hard-to-reach area	S	2.60	0.79
44	Opened the wrong panel to get access for a job	S or M	2.47	0.74
36	Not used the checklist when starting an engine	V	2.43	1.39
19	Done a job a better way than that in the manual	V	2.41	0.94
16	Turned a blind eye to minor defect when correcting it would have delayed an aircraft	V	2.39	1.03
41	Been misled because someone gave you wrong information about the stage of progress of a job	M	2.25	0.87
31	Disconnected a part or system to make a job easier, but not documented the disconnection	V	2.22	0.98
17	Not referred to the parts catalogue when selecting a part	V	2.11	1.10
6	Forgotten to sign-off a task	L	2.09	0.78
30	Sign a job on behalf of someone else without checking it	V	2.06	1.11
8	Had difficulty with a task because you misunderstood how a particular aircraft system worked	M	2.03	0.78
38	Corrected an error made by another engineer, without documenting what you had done, to avoid getting them into trouble	V	2.00	0.91
5	Made a mistake on a job because you hadn't been shown how to do it properly	M	1.84	0.73
18	Not made a system safe before working on it, or in its vicinity	V	1.79	0.91
34	Done an unfamiliar job, despite being uncertain whether you were doing it correctly	V	1.79	0.79
37	Done an engine run in a part of the airport where this was not permitted (or at a time when this was not permitted)	V	1.70	1.01
9	Started to do a job the wrong way because you didn't realize that the aircraft or system was different to what you were used to	M	1.64	0.70
2	Left a tool or a torch behind in an aircraft	L	1.63	0.66
45	Lost a component part-way through a job	L	1.55	0.72
24	Activated the wrong cockpit control by mistake	M	1.53	0.62
39	Rigged a system without the proper rigging boards or tooling	V	1.51	0.81
48	Been interrupted part-way through a job and forgotten to return to it	L	1.51	0.73
32	Manufactured a component without formal drawings or approval	V	1.48	0.79
47	Assembled a component or system incorrectly because the documentation was unclear or misleading	M	1.47	0.63
3	Accidentally left a rag or rubbish item behind in an aircraft	L	1.46	0.60

continued

Table 3. *continued*

Item	Description	Type*	Mean	SD
13	Decided not to do functional check or engine run because of a lack of time	V	1.44	0.73
20	Signed off a task before it had been completed	V	1.44	0.71
26	Selected the wrong part to install	S or M	1.42	0.63
14	Not referred to the maintenance manual or other approved documentation on an unfamiliar job	V	1.42	0.64
25	Adjusted or rigged a system incorrectly because the documentation was unclear or misleading	M	1.42	0.63
1	Tried to move an aircraft with the brakes still applied	L	1.41	0.66
7	Not noticed that someone was near a system which you were about to activate (e.g. starting an engine)	L or M	1.40	0.60
40	Activated a system (such as hydraulics) and been surprised to find that cockpit controls had been moved while the system was off	M	1.39	0.62
10	Installed a part the wrong way	S or M	1.37	0.56
42	Started to work on the wrong engine on a multi-engine aircraft	S or M	1.36	0.58
21	Forgotten to re-connect a fuel or oil line, a cable or electrical connection	L	1.31	0.52
29	Intentionally over-torqued a bolt to make it fit	V	1.22	0.49
23	Left connections finger-tight because you forgot to tighten them	L	1.21	0.45
27	Found a part (e.g. in your pocket) after a job was completed	L	1.20	0.46
28	Cut the wrong wire or cable by mistake	S	1.17	0.41
35	Taxied an aircraft into a hangar	V	1.15	0.53
46	Added the wrong fluid to a system	S	1.03	0.18
22	Accidentally started an engine	S	1.02	0.16

*S = Slip; L = Lapse; V = Violation; M = Mistake.

Factor 3 was labelled 'mistakes', as of the nine items which are listed as loading on this factor in table 4, all but one represented misunderstandings or other difficulties in the planning of behaviour. The exception was item 43, which was considered to be an action slip. This factor accounted for 9.1% of the variance. The average frequency rating of factor 3 items was 1.93.

The items associated with factor 4 appeared to represent largely 'exceptional violations'. Lawton (1998) describes such violations as rare actions that occur in unusual situations. Of the five items which loaded on this factor, four were particularly dangerous violations and the average frequency ratings of the five items was 1.60, which is less than that for factor 1 items. Factor 4 accounted for 5.9% of the total variance.

3.3. *Predictors of factors*

Demographic variables were entered simultaneously into regression equations to predict factor scores. Routine and exceptional violations were associated significantly with age at the 0.01 level, with younger workers generally reporting a higher level of such behaviour. Skill-based errors and mistakes, however, were not related significantly to age. Both varieties of violations were associated with regional airlines

Table 4. Factor loadings for MBQ items.

Item	Description	Type*	Factor 1	Factor 2	Factor 3	Factor 4
1	Tried to move an aircraft with the brakes still applied	L				0.50
2	Left a tool or a torch behind in an aircraft	L		0.56		
3	Accidentally left a rag or rubbish item behind in an aircraft	L		0.62		
4	Been misled by confusing documentation	M			0.45	
5	Made a mistake on a job because you hadn't been shown how to do it properly	M		0.50		
6	Forgotten to sign-off a task	L		0.45		
7	Not noticed that someone was near a system which you were about to activate (e.g. starting an engine)	L or M		0.45		
8	Had difficulty with a task because you misunderstood how a particular aircraft system worked	M		0.40		
9	Started to do a job the wrong way because you didn't realize that the aircraft or system was different to what you were used to	M	0.50			
10	Installed a part the wrong way	S or M		0.59		
11	Done a job without the correct tool or equipment	V	0.53			
12	Not referred to the maintenance manual or other approved documentation on a familiar job	V	0.68			
13	Decided not to do functional check or engine run because of a lack of time	V	0.45			
14	Not referred to the maintenance manual or other approved documentation on an unfamiliar job	V	0.43			
15	Not documented a small job	V	0.69			
16	Turned a blind eye to minor defect when correcting it would have delayed an aircraft	V	0.68			
17	Not referred to the parts catalogue when selecting a part	V	0.60			
18	Not made a system safe before working on it, or in its vicinity	V	0.59			
19	Done a job a better way than that in the manual	V	0.42			
20	Signed off a task before it had been completed	V	0.47			
21	Forgotten to re-connect a fuel or oil line, a cable or electrical connection	L		0.54		
22	Accidentally started an engine	S				

continued

Table 4. *continued*

Item	Description	Type*	Factor 1	Factor 2	Factor 3	Factor 4
23	Left connections finger-tight because you forgot to tighten them	L		0.51		
24	Activated the wrong cockpit control by mistake	M			0.40	
25	Adjusted or rigged a system incorrectly because the documentation was unclear or misleading	M			0.56	
26	Selected the wrong part to install	S or M		0.41	0.42	
27	Found a part (e.g. in your pocket) after a job was completed	L		0.45		
28	Cut the wrong wire or cable by mistake	S				
29	Intentionally over-torqued a bolt to make it fit	V				
30	Sign a job on behalf of someone else without checking it	V	0.62			
31	Disconnected part or system to make a job easier, but not documented the disconnection	V	0.62			
32	Manufactured a component without formal drawings or approval	V				0.57
33	Pulled a circuit breaker but decided not to tag it	V	0.61			
34	Done an unfamiliar job, despite being uncertain whether you were doing it correctly	V	0.44			
35	Taxied an aircraft into a hangar	V				0.66
36	Not used the checklist when starting an engine	V	0.50			0.49
37	Done an engine run in a part of the airport where this was not permitted (or at a time when this was not permitted)	V	0.41			
38	Corrected an error made by another engineer, without documenting what you had done, to avoid getting them into trouble	V	0.41			
39	Rigged a system without the proper rigging boards or tooling	V				0.43
40	Activated a system (such as hydraulics) and been surprised to find that cockpit controls had been moved while the system was off	M			0.51	
41	Been misled because someone gave you wrong information about the stage of progress of a job	M			0.63	
42	Started to work on the wrong engine on a multi-engine aircraft	S or M				
43	Dropped an object into a hard-to-reach area	S			0.50	
44	Opened the wrong panel to get access for a job	S or M			0.55	
45	Lost a component part-way through a job	L				
46	Added the wrong fluid to a system	S				
47	Assembled a component or system incorrectly because the documentation was unclear or misleading	M			0.58	
48	Been interrupted part-way through a job and forgotten to return to it	L		0.46		

*S = Slip; L = Lapse; V = Violation; M = Mistake.

and charter operations. Workers at major airlines, however, tended to report routine violations but not exceptional violations (table 5).

3.4. *Prediction of involvement in safety occurrences*

The majority of respondents reported that they had not been injured at work in the previous 12 months. However, just over 30% had been injured once, or more than once (table 6). Approximately two-thirds of respondents reported that they had been involved in a quality problem in the previous 12 months.

Routine violations were the strongest predictors of involvement in quality incidents, although mistakes and exceptional violations were significantly related to involvement in such incidents at the 0.05 level (table 7). Skill-based errors fell short of being significant predictors of quality incidents at the 0.05 level.

The score for skill-based errors was the only factor score that received a significant β weight in predicting work injuries using the 0.05 level of significance (table 8). The β weights for mistakes, routine violations and exceptional violations were well short of significance.

4. Discussion

The factor analysis of the MBQ data has provided further evidence for the three-way distinction between unintended errors, mistakes, and violations proposed by Reason (1990) and supported subsequently by the DBQ research of Reason *et al.* (1990), Parker *et al.* (1995) and Åberg and Rimmöe (1998). The demonstration of this distinction in a context other than road safety suggests that it may be applicable in a variety of safety environments. Additionally, the factor analysis has implied that there may be a distinction between two forms of violations in aircraft maintenance. Using the terminology of Lawton (1998), the first class of violations appears to represent 'routine' violations. Such actions tend to be frequent and relatively benign shortcuts in familiar situations. The second class of violation identified in the current study appears to fit Lawton's description of 'exceptional' violations. These are risky but low frequency violations, which occur in response to unusual circumstances.

Consistent with the findings of Parker *et al.* (1995), the current study has further suggested that violations (particularly routine ones) have an important connection with maintenance quality incidents affecting the safety of aircraft. The demonstration of this relationship serves to reinforce the link between violations and safety in hazardous environments. Mistakes were also associated with quality incidents, although at a lower level of significance, and while the results also suggested a link between skill-based errors and quality occurrences, this association fell short of statistical significance.

Nevertheless, while violations were most strongly associated with quality incidents, they may not necessarily be the immediate precursor of a safety event. Lawton and Parker (1998) note that violations may set the scene for an accident by increasing the probability of error, or by reducing the margin of safety should an error occur. For example, the omission of a functional check at the completion of maintenance work may not in itself lead to a problem, but could permit an earlier lapse to go undetected. According to Battmann and Klumb (1993) people weigh the potential costs and benefits of a course of action before they decide to violate. If indeed violations frequently serve as 'amplifiers' of errors rather than primary hazards in their own right, then their costs, being indirect, may tend to be overlooked. The benefits of violations, however (such as time saved) tend to be

Table 5. Predictors of factor scores.

Predictor	Routine violations (Overall R = 0.230) β	P	Skill-based errors Overall R = 0.141 β	P	Mistakes Overall R = 0.106 β	P	Exceptional violations Overall R = 0.425 β	P
Age	−0.299	0.000	0.014	0.839	−0.081	0.225	−0.159	0.009
Years in industry	0.137	0.038	−0.119	0.076	0.018	0.785	0.124	0.042
Supervisory position	0.025	0.399	−0.018	0.563	−0.007	0.819	0.065	0.019
Major airline	0.248	0.002	0.052	0.508	0.068	0.399	−0.038	0.609
Regional airline	0.195	0.000	0.097	0.077	0.109	0.050	0.219	0.000
Charter operator	0.255	0.000	0.099	0.104	0.096	0.123	0.311	0.000
General aviation	0.117	0.034	0.075	0.162	0.033	0.547	0.192	0.000

Table 6. Frequency of workplace injuries and quality incidents in the previous year.

Outcome	None	One	More than one
Maintenance quality problems*	401 (32.9%)	211 (17.3%)	606 (49.8%)
Injuries at work**	860 (67.9%)	275 (21.7%)	132 (10.4%)

* (Excludes 74 respondents who did not answer this question).
** (Excludes 25 respondents who did not answer this question).

Table 7. Prediction of involvement in maintenance quality incidents involving damage or disruption to an aircraft (Overall $R = 0.400$).

Step	Predictor	R^2	Increment	β	Significance
1	Age	0.038	0.038	−0.133	0.000
2	Major airline			0.130	0.102
	Regional airline			0.041	0.457
	General aviation			−0.013	0.813
	Charter	0.047	0.009	0.009	0.886
3	Skill-based errors			0.077	0.051
	Mistakes			0.102	0.011
	Routine violations			0.152	0.000
	Exceptional violations	0.160	0.113	0.098	0.015

Table 8. Prediction of being injured at work (Overall $R = 0.189$).

Step	Predictor	R^2	Increment	β	Significance
1	Age	0.008	0.008	−0.055	0.062
2	Major airline	0.012	0.004	−0.023	0.785
	Regional airline			−0.020	0.735
	General aviation			−0.077	0.170
	Charter			−0.022	0.726
3	Skill-based errors	0.036	0.024	0.098	0.018
	Mistakes			0.043	0.309
	Routine violations			0.052	0.236
	Exceptional violations			0.027	0.520

direct, and possibly come to mind more readily to a person who is contemplating a contravention of a rule. Therefore, workers may need to be educated about the hidden costs of seemingly insignificant violations, and particularly how violations can combine with errors to lead to occurrences. Particularly in environments where people work in teams and work-in-progress is handed from one shift to another, violations can set the conditions for misunderstandings. Hence the rate of violations may prove to be a useful measure of the accident risk facing an organization.

The current results suggest further that incidents that result in worker injury may have quite different origins to incidents that affect the quality of work. Despite their association with work quality incidents, violations showed no association with workplace injuries. On the other hand, skill-based errors were the only form of unsafe act which was significantly associated with worker injury. Those respondents who reported having been injured at work also tended to report more skill-based errors. The relationship between skill-based errors and injury in aircraft maintenance is consistent with the findings of Williamson and Feyer (1990) and Salminen and Tallberg (1996) who identified skill-based errors, as the most common form of unsafe behaviour preceding workplace accidents.

The particular behavioural correlates of injuries and quality incidents suggest that different intervention strategies are required to lessen the frequency of each type of occurrence. Interventions directed at workplace injury are likely to require a focus on skill-based errors, the circumstances that permit such errors and the conditions that exacerbate their consequences. This is not to say that skill-based behaviour is inherently error-prone, but rather that the frequent involvement of skill-based behaviour in accident causation reflects the prevalence of such behaviour in work settings (Hobbs and Williamson, 2002). Given that skill-based behaviour is, by definition, beyond conscious awareness (Reason 1990), the most appropriate strategy to address skill-based errors may be to target the physical environment of the workplace, rather than attempting to change human behaviour (Feyer *et al.* 1997). Such interventions could involve changes to the workplace in order to contain the consequences of errors, such as physical barriers between hazards and workers, possibly in the form of improved personal protective equipment.

The present findings, however, suggest that in order to address maintenance quality incidents it is necessary to direct interventions at violations and the factors that promote them. Non-compliance with safety procedures appears to reflect a combination of organizational and individual factors (DeJoy 1996, Lawton 1998). Hence interventions to reduce the incidence of violations need to be targeted at both the organizational and personal level. In the current study, support for the view that violations are associated with personal variables comes from the finding that younger workers reported a significantly higher incidence of routine violations than older workers, even though the frequency of reported errors did not change with age. This result is consistent with previous findings that rule-violating and risky behaviour in a variety of contexts is commonly associated with youth (Jessor 1987). According to DeJoy (1996), for safe work behaviour to occur, the individual must first appraise the hazards presented by a situation, and it is at this stage that personal beliefs about risk influence safety compliance. While some unsafe behaviour may arise from an intention to take known risks, other forms of unsafe behaviour occur when the person lacks the experience necessary to make accurate appraisals of risk. For example, young male drivers tend to underestimate the risk of certain traffic situations, while simultaneously overestimating their own driving abilities (McDonald 1994). If indeed the higher rate of violations among younger workers reflects poor judgements of risk, then this would suggest that a reduction in the frequency of violations among these workers could be achieved by focusing on the hazard appraisal stage of safety compliance. Specifically, younger workers could benefit from accurate information on the risks of non-compliance with safety procedures.

It would be misguided, however, to focus on the personal characteristics of rule violators and ignore the context in which violations occur. Mason *et al.* (1995), DeJoy (1996) and Lawton (1998) each trace the root causes of violations to the nature of the organization itself. For example, Mason *et al.* (1995) maintain that violations are likely to be committed by well-intentioned staff who are trying to get the job done in the face of organizational challenges such as time shortages or a lack of equipment. While not all violations are necessarily associated with such factors, it is clear that organizational-level issues need to be addressed if violations are to be reduced.

An aircraft hangar is a highly regulated workplace and mechanics are expected to carry out their duties while observing legal requirements, manufacturer's maintenance manuals, company procedures and unwritten norms of safe behaviour. McDonald *et al.* (1997: 59) note that aircraft mechanics are 'forbidden from using professional skill or judgement and commanded to follow the letter of the procedure regardless of its practicability'. Given the highly rule-bound nature of the occupation, it is perhaps not surprising that the critical incident interviews through which the MBQ items were generated resulted in the survey containing a greater number of routine violations than other forms of unsafe behaviour. Undoubtedly, the factor structure that emerged partly reflected this. Nevertheless, in the current study, violations carried significantly less weight in terms of overall questionnaire variance explained than was the case in the DBQ studies of Reason *et al.* (1990) and Åberg and Rimmöe (1998). Reason *et al.* (1990) reported that the violation factor of the DBQ accounted for 22.6% of the total variance, while the dangerous error factor and the harmless error factor accounted for 6.5 and 3.9% of the variance, respectively. Åberg and Rimmöe (1998) likewise indicated that their violation factor explained 23.6% of the variance, with their remaining factors accounting for 10.6, 5.3 and 4.5% of the variance. In the current study, the proportion of variance accounted for by the four unrotated factors was very similar to the pattern of results reported by Reason *et al.* (1990) and Åberg and Rimmöe (1998). The first unrotated MBQ factor accounted for 23.5% of the variance, the second 6.4%, the third 4.1% and the fourth 3.3%. However, after rotation, the variance was more evenly distributed between the four factors. While the results of Reason *et al.* (1990) and Åberg and Rimmöe (1998) give prominence to violations in terms of variance explained, the current findings indicate that a range of unsafe acts, including violations, are important in this regard. Future versions of the MBQ, however, could benefit by the addition of a greater range of behaviours, particularly skill-based errors and serious or exceptional violations.

It would also be preferable to obtain future MBQ data on a greater proportion of the maintenance population. Most of the mechanics who received the MBQ did not return a completed survey, despite the incentives that were offered. Unfortunately, no information is available for these non-respondents and it is possible that those who returned the questionnaire are in some manner unrepresentative of the total population. Despite the difficulty in sampling, however, the current study produced results broadly consistent with previous DBQ studies.

In conclusion, the current study has not only provided support for Reason's (1990) tripartite classification of unsafe acts, but has indicated that to understand the origins of accidents we need to understand the origins of errors and violations. Lawton and Parker (1998) propose that there are two unsafe act paths to accidents, an error pathway and a violation pathway, each related to different organizational deficiencies and requiring different accident prevention strategies. The current study has suggested that not only are there two such pathways, but also that each may tend to lead to different safety outcomes. In the context of aircraft maintenance, violations are most strongly associated with quality incidents, while skill-based errors are correlated with injuries. Successful safety interventions must be based on a clear delineation of the unsafe act pathways and the individual and organizational correlates of particular unsafe acts.

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